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Contribution of SLR observations to LEO and GNSS satellites for validating and improving LAGEOS-based parameters

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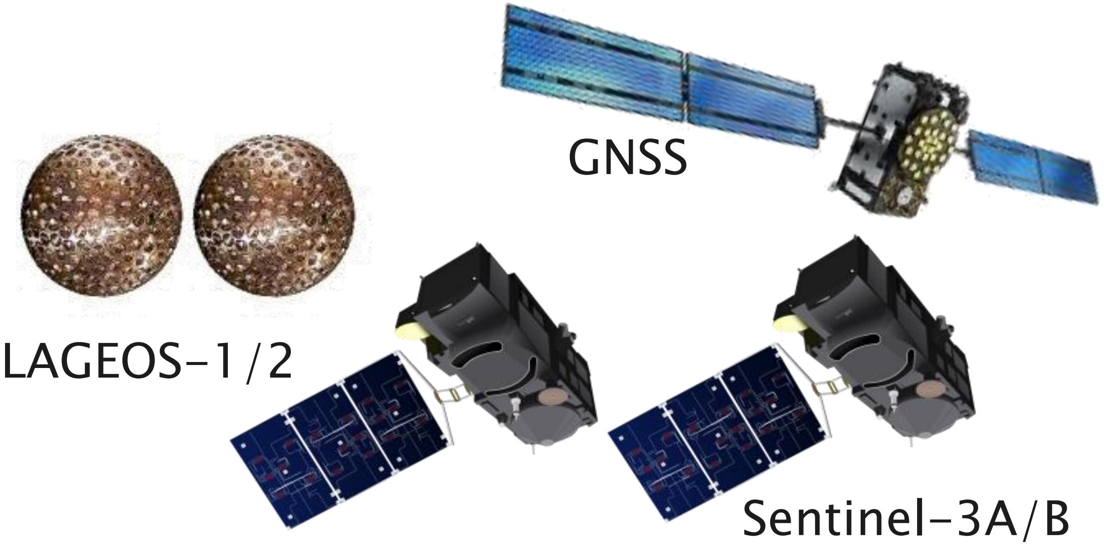
Motivation

Standard SLR solution

LAGEOS-1/2



- Currently, the SLR reference frame is based on **2 LAGEOS and 2 Etalon** satellites. The contribution of **Etalon is almost negligible**.
- All new GNSS satellites and many LEO satellites are equipped with laser retroreflector arrays.
- **No** active satellites, such as **GNSS or LEO, are used for the ITRF definition**, e.g., for the estimation of GNSS station coordinates, geocenter coordinates or Earth rotation parameters.
- **Some stations**, e.g., from the Russian SLR network, **provide much more SLR observations to GNSS** than to LAGEOS, whereas e.g., **Arequipa provides more observations to LEOs**
- Between 2014 and 2018, ILRS conducted a series of **intensive campaigns tracking GNSS** or LEOs
- Today, there are about **50 active GNSS and 25 active LEO satellites** tracked by ILRS stations

The goal of this study is to show that SLR tracking to active satellites can be used for the determination of global geodetic parameters. We focus on Sentinel-3A/B.

Sentinel-3A/B

Courtesy of ESA/EUMETSAT

Sentinel 3	3A	3B
Begining	16-02-2016	25-04-2018
End	7 years (ext. possible to 12 ys)	
Height	815 km	
Inclination	98.65°	
Mass	1150 kg	
Full coverage	27 days	
Orbit	Tandem, then 3B arg. of latit. shifted by +/-140° w.r.t. 3A	

- Measures sea surface topography; sea and land surface temperatures; ocean and land surface color
- High-quality GPS receiver -> high-quality GPS orbits, which are required for the altimetry mission (3 cm requirement, 2 cm target accuracy for the radial component)
- Laser retroreflector array onboard for the validation of GPS-based orbits

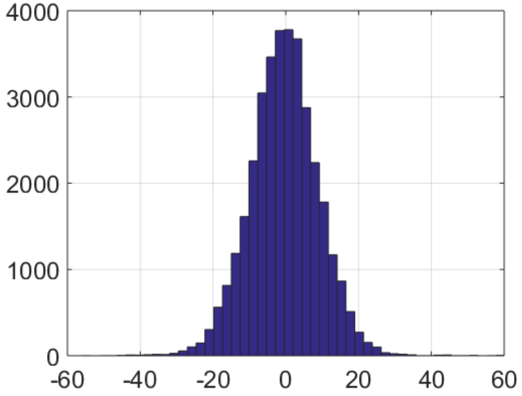
but

high-quality SLR observations can also be used for the calibration of SLR biases and the determination of geodetic parameters: station coordinates, Earth rotation parameters, geocenter motion, etc.

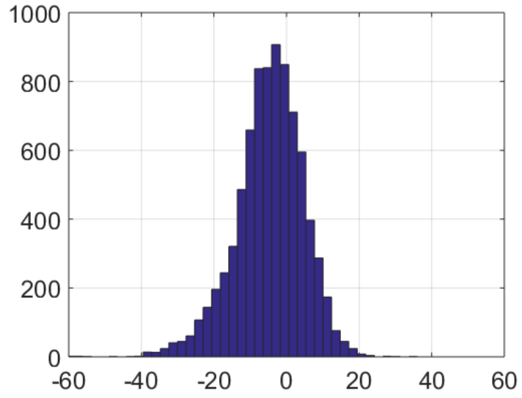
Orbit modeling details: https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-3/ground-segment/pod/documentation

Sentinel-3A/B – AIUB orbit validation using SLR data (in SLRF2014)

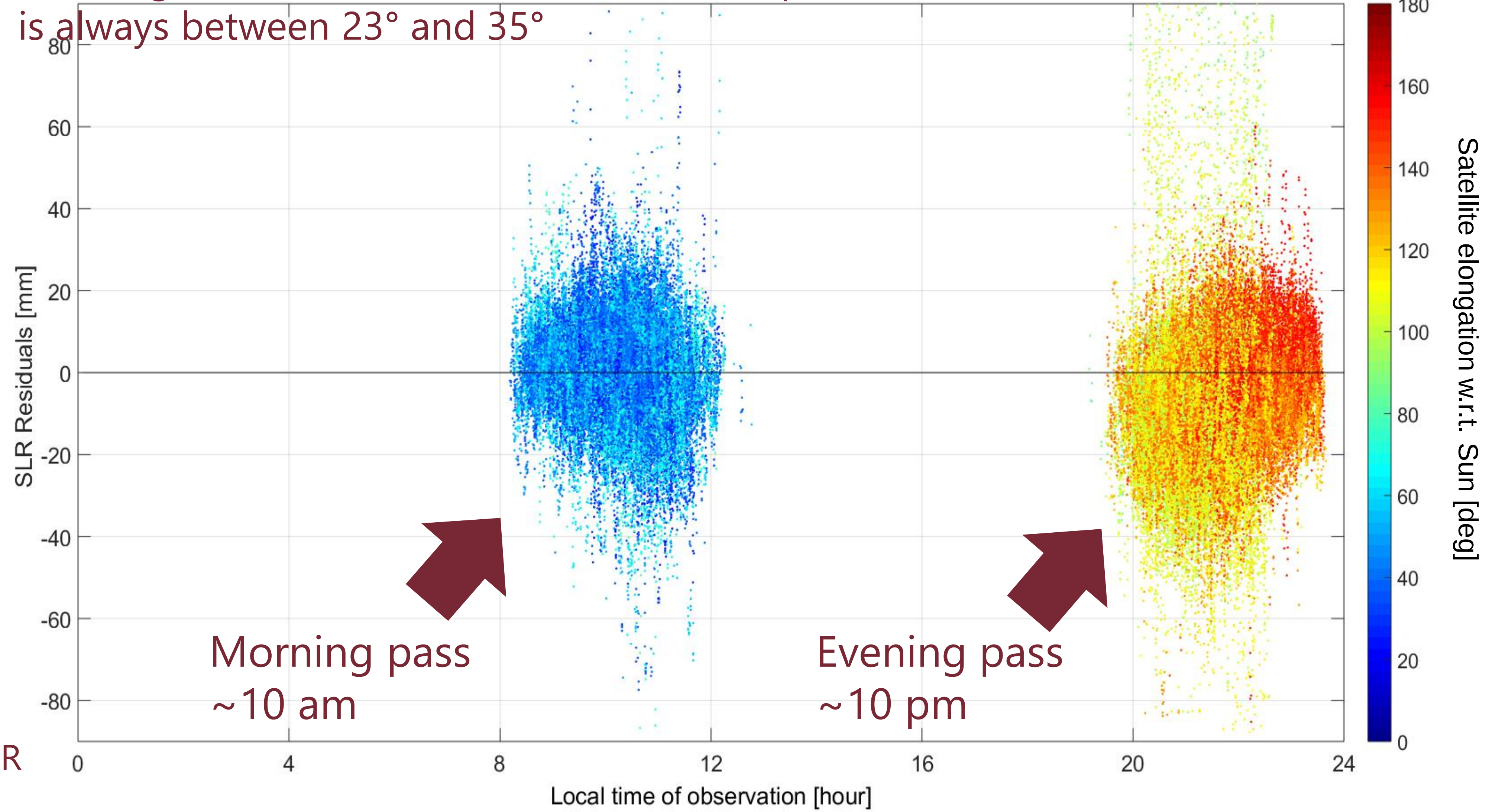
Sentinel-3 satellites are in Sun-synchronous orbits beta angle (Sun elevation above the orbital plane) is always between 23° and 35°



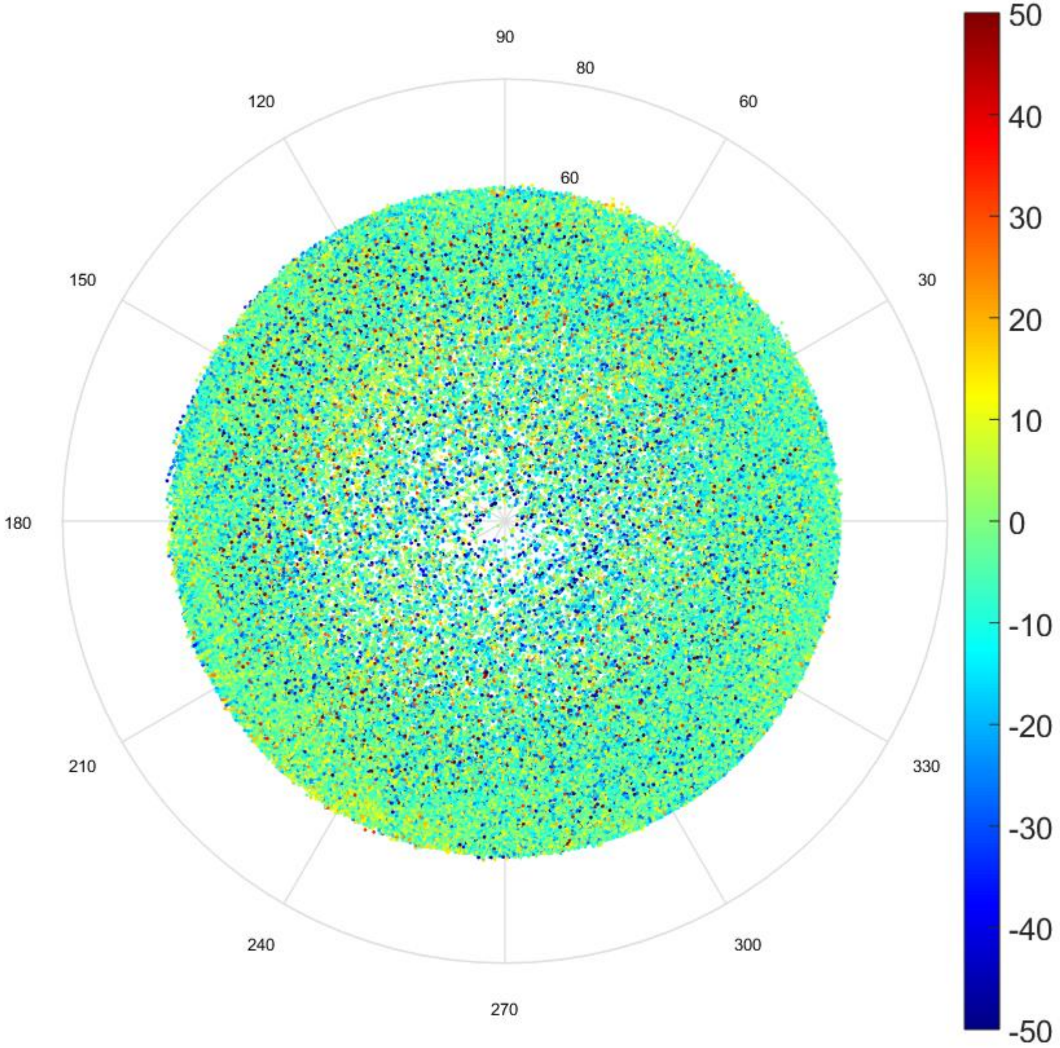
Yarragadee RMS of SLR residuals 9.4 mm



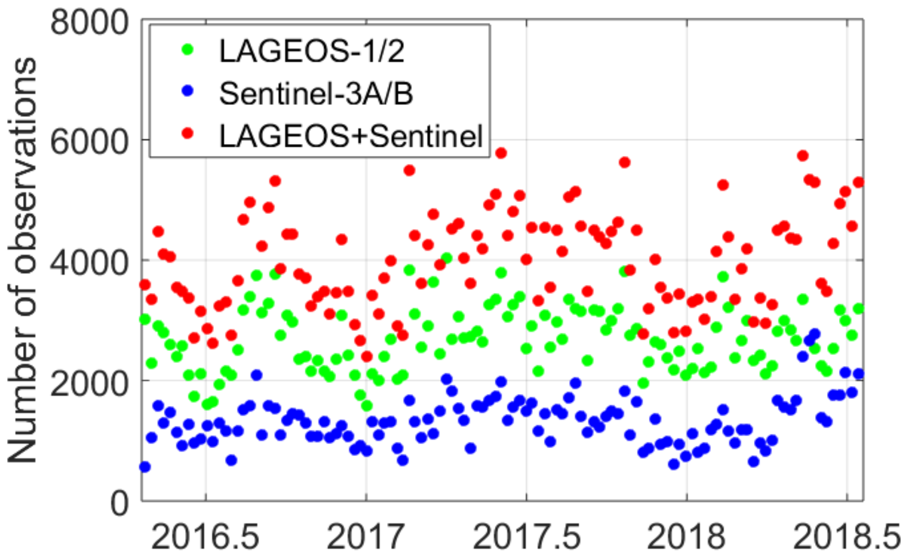
Herstmonceux RMS of SLR residuals 9.7 mm

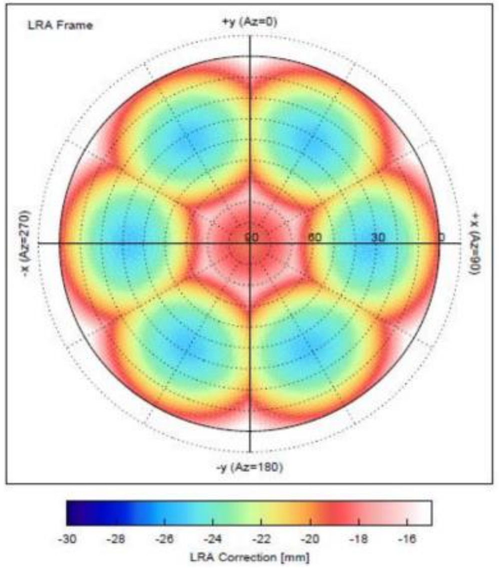


Sentinel-3A/B – retroreflectors and tracking restrictions



Nadir view from Sentinel-3A
Colors: SLR residuals in mm





Restricted tracking: 1.7nJ/cm^2 at the satellite location and for a PRF < 22 Hz or for higher 1.7nJ/cm^2 * (22Hz / PRF). Tracking with energies above the threshold shall be prohibited +5deg/-5deg along the trajectory and around the highest elevation point.

Courtesy of ESA/EUMETSAT

Concept of the combination of SLR observations to LAGEOS, LEO, and GNSS

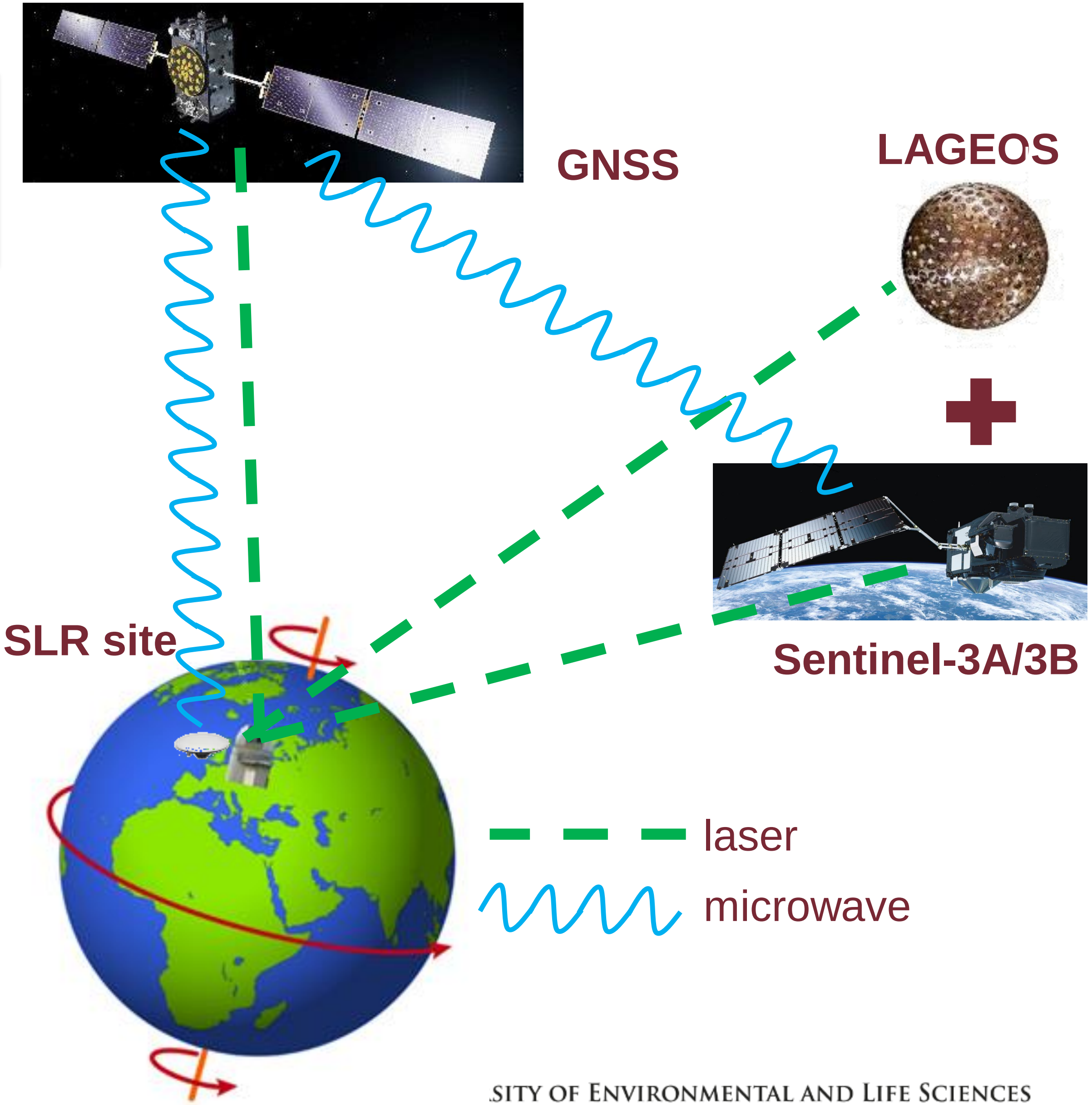
SLR data to active satellites (LEO, GNSS) + SLR data to geodetic satellites (LAGEOS-1/2)

↓

Station coordinates	Geocenter
ERPs	Orbits
Biases	

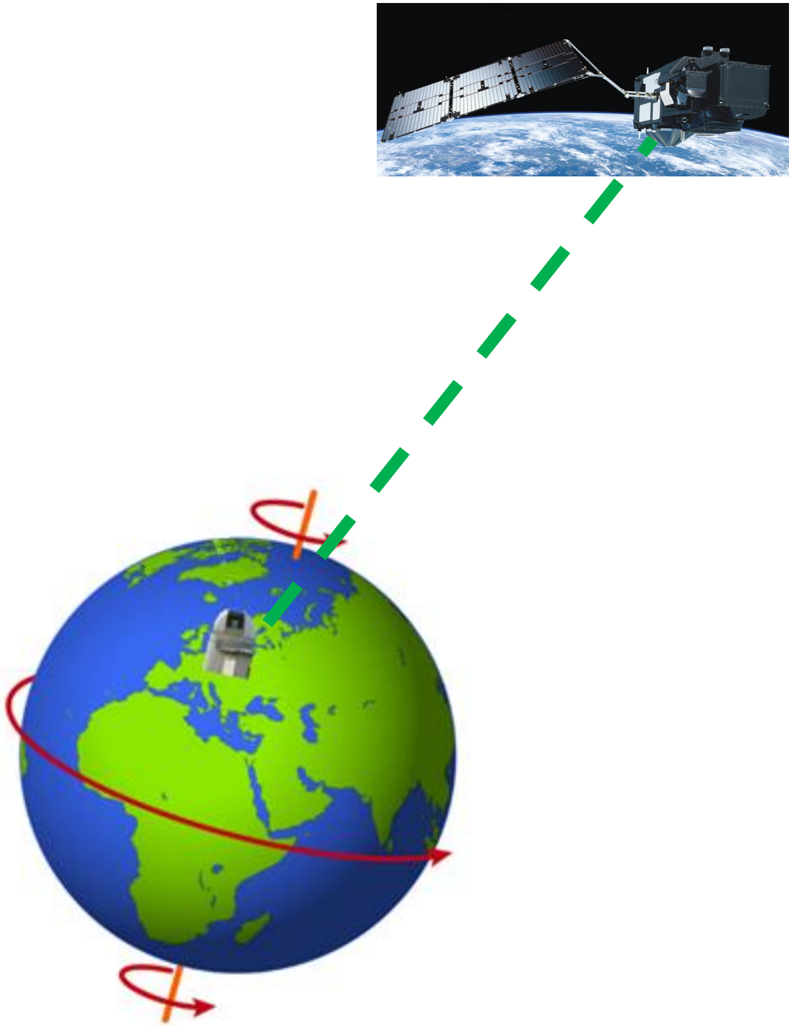
↓

Combined solutions



Solutions based on SLR observations to Sentinel-3A/B

Sentinel-3A/3B
(fixed GPS-based orbits)



Test 1: <u>network constraints: no-net-translation (NNT) and not-net-rotation (NNR);</u>
other parameters unconstrained (ERPs, station coordinates, geoc.)

→ Station coordinates, ERPs, geocenter

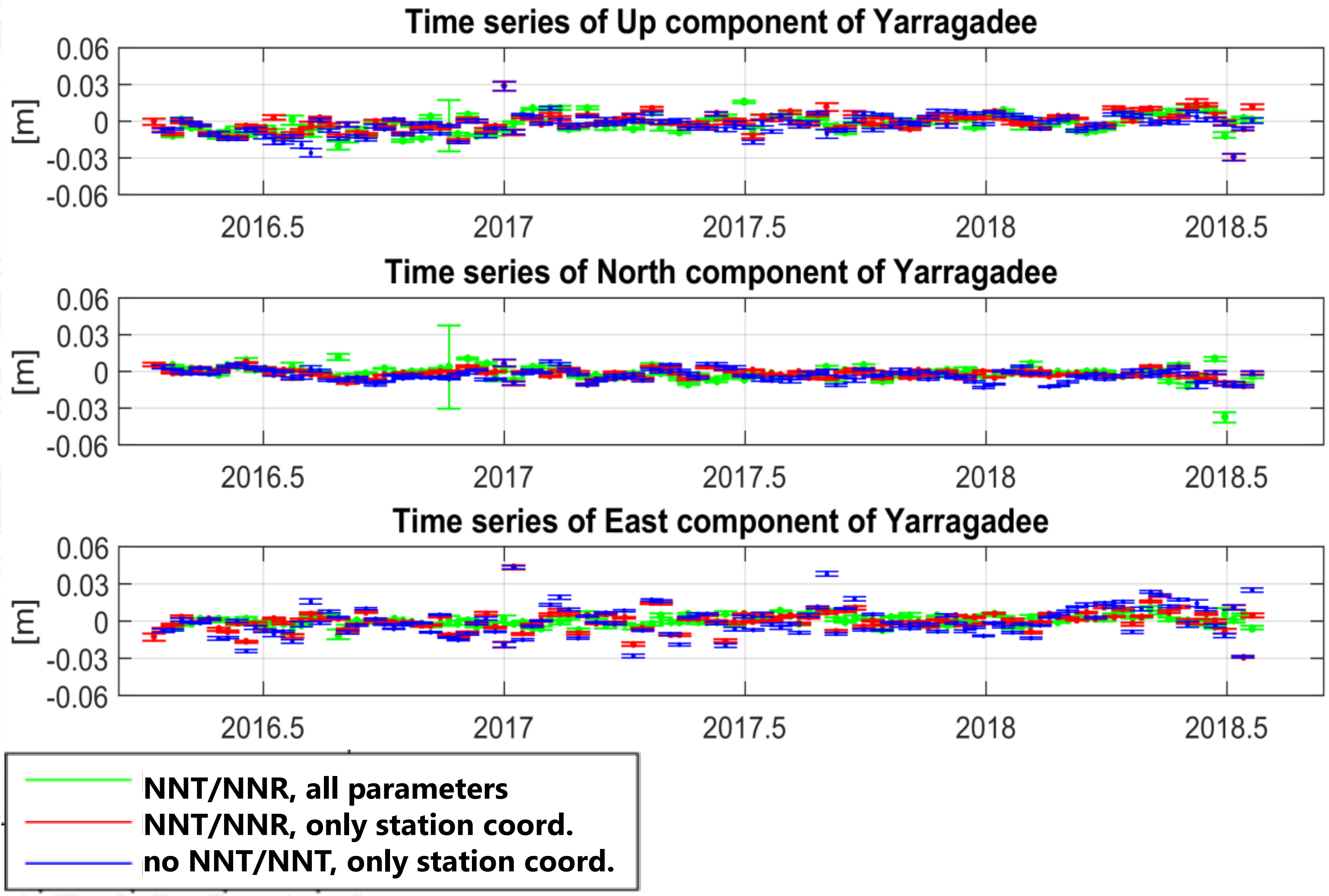
Test 2: <u>network constraints: no-net-translation (NNT) and not-net-rotation (NNR);</u>
only station coordinates estimated

→ Station coordinates

Test 3: <u>network without constraints: (free network solution);</u>
only stations coordinates estimated

→ Station coordinates
<u>"SLR-PPP"</u>

7-day solutions for Sentinel-3A/B (fixed GPS orbits) – station coordinates

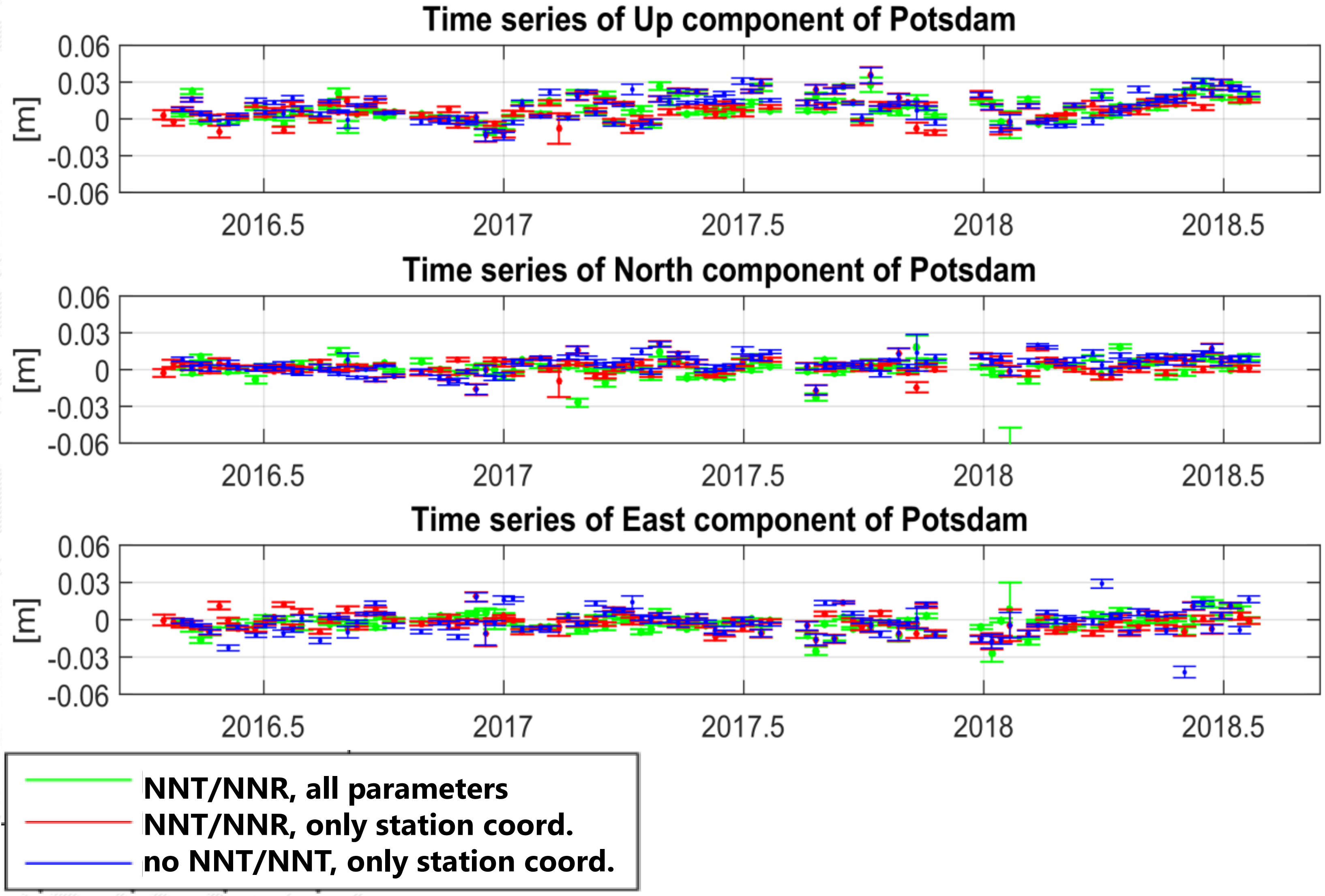


Station coordinate repeatability for Yarragadee falls between 5 and 9 mm for individual components.

Even the solution without network constraining (test 3, blue) provides proper station coordinates.

Test 3 solution can be named ``**SLR-PPP**” because it fully relies on the orbit quality and the quantity and quality of SLR observations.

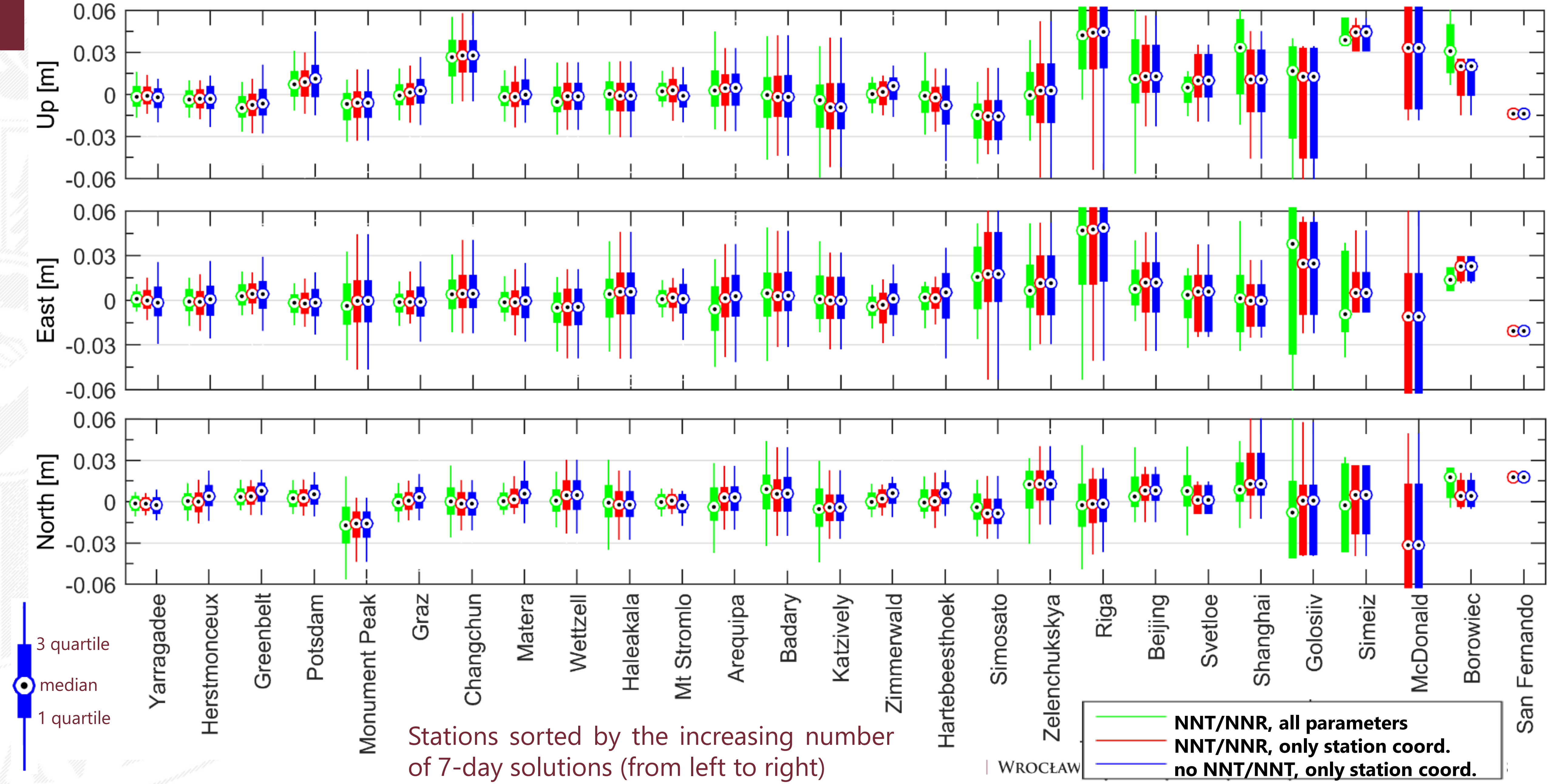
7-day solutions for Sentinel-3A/B (fixed GPS orbits) – station coordinates



Station coordinate repeatability for Potsdam falls between 7 and 14 mm.

The positioning of SLR stations with the accuracy at the level of 1 centimeter is possible!
Even without network constraining (test 3).

7-day (7x1-day) solutions for Sentinel-3A/B – station coordinates

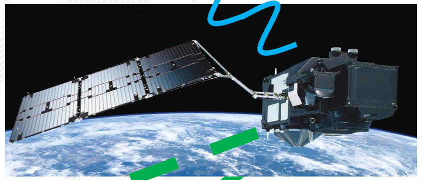


Stations sorted by the increasing number of 7-day solutions (from left to right)

The issue of the reference frame differences

Test 1 with NNT/NNR constraints

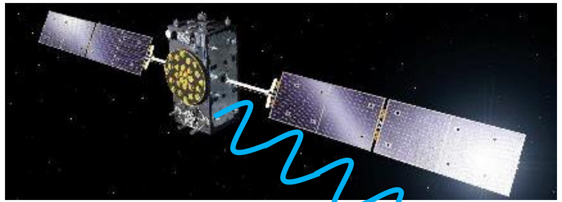
GNSS – IGS14
integrated around
Center-of-Figure (CoF)



SLR sites in SLRF2014
(CoF by NNT/NNR)

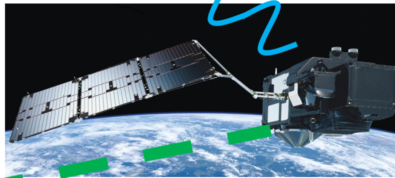
LEO – IGS14, but pseudo-stochastic orbit parameters are estimated –> larger flexibility, close representation of the Earth's Center-of-Mass (CoM)

Test 3 no network constraints - SLR-PPP

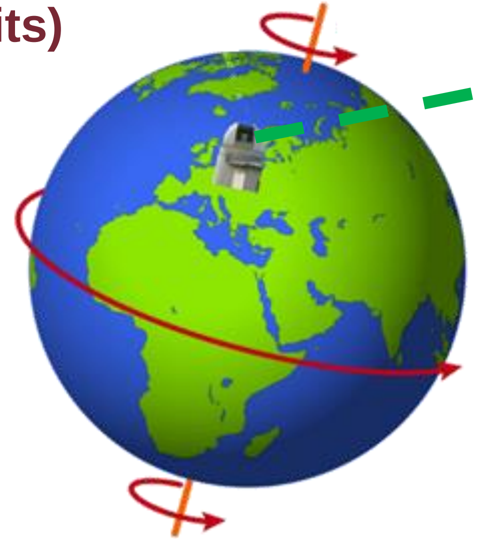


GNSS – IGS14
integrated around
Center-of-Figure (CoF)

SLR sites IGS14 (reference frame transferred through LEO orbits)



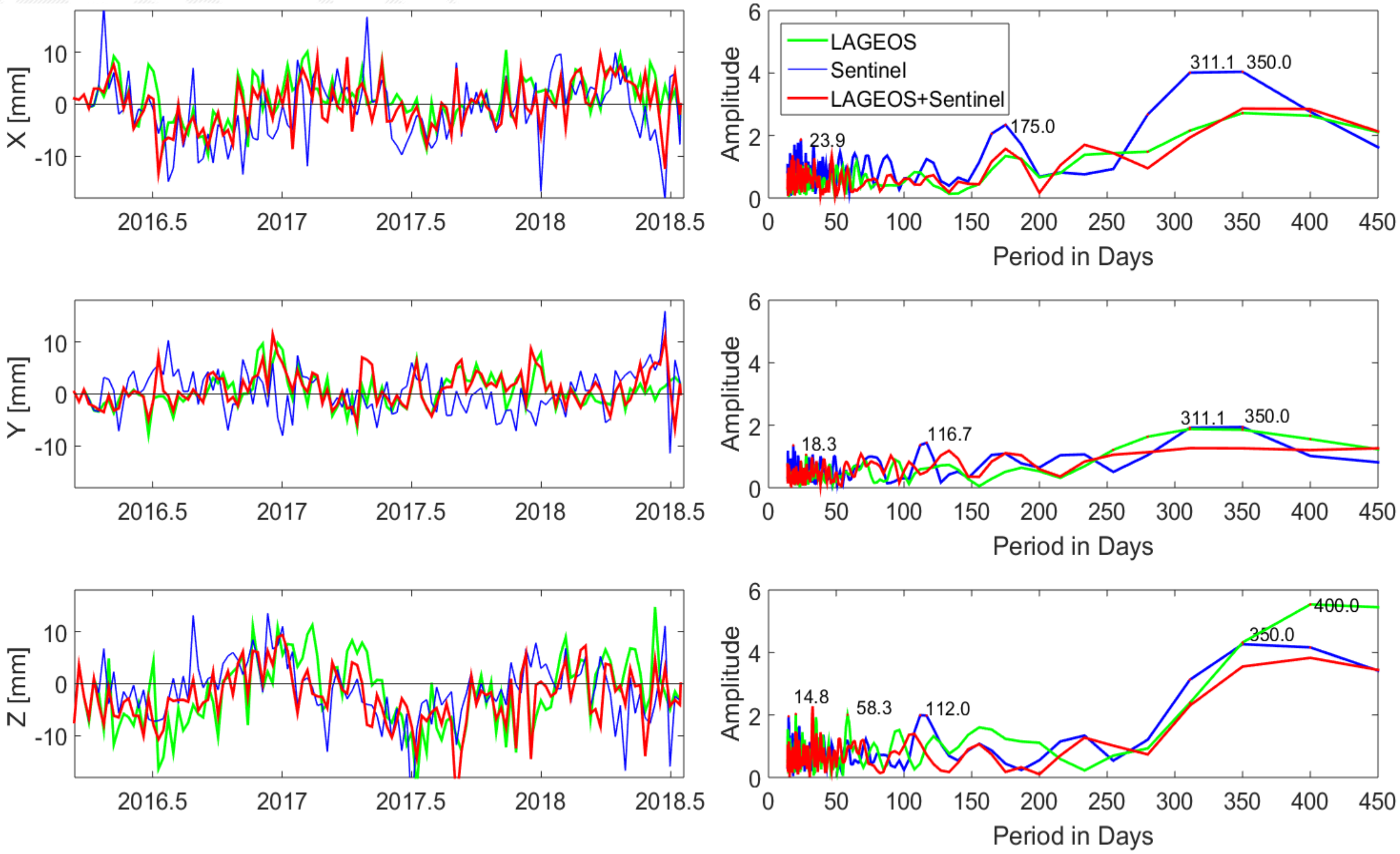
LEO – IGS14, reduced



In SLR-PPP (test3) SLR station coord. are in IGS14

CoM vector w.r.t. CoF represents geocenter motion, but to what extent IGS14 and SLRF2014 are consistent?

Geocenter coordinates based on Sentinel 3A/3B, LAGEOS-1/2 and all sats.



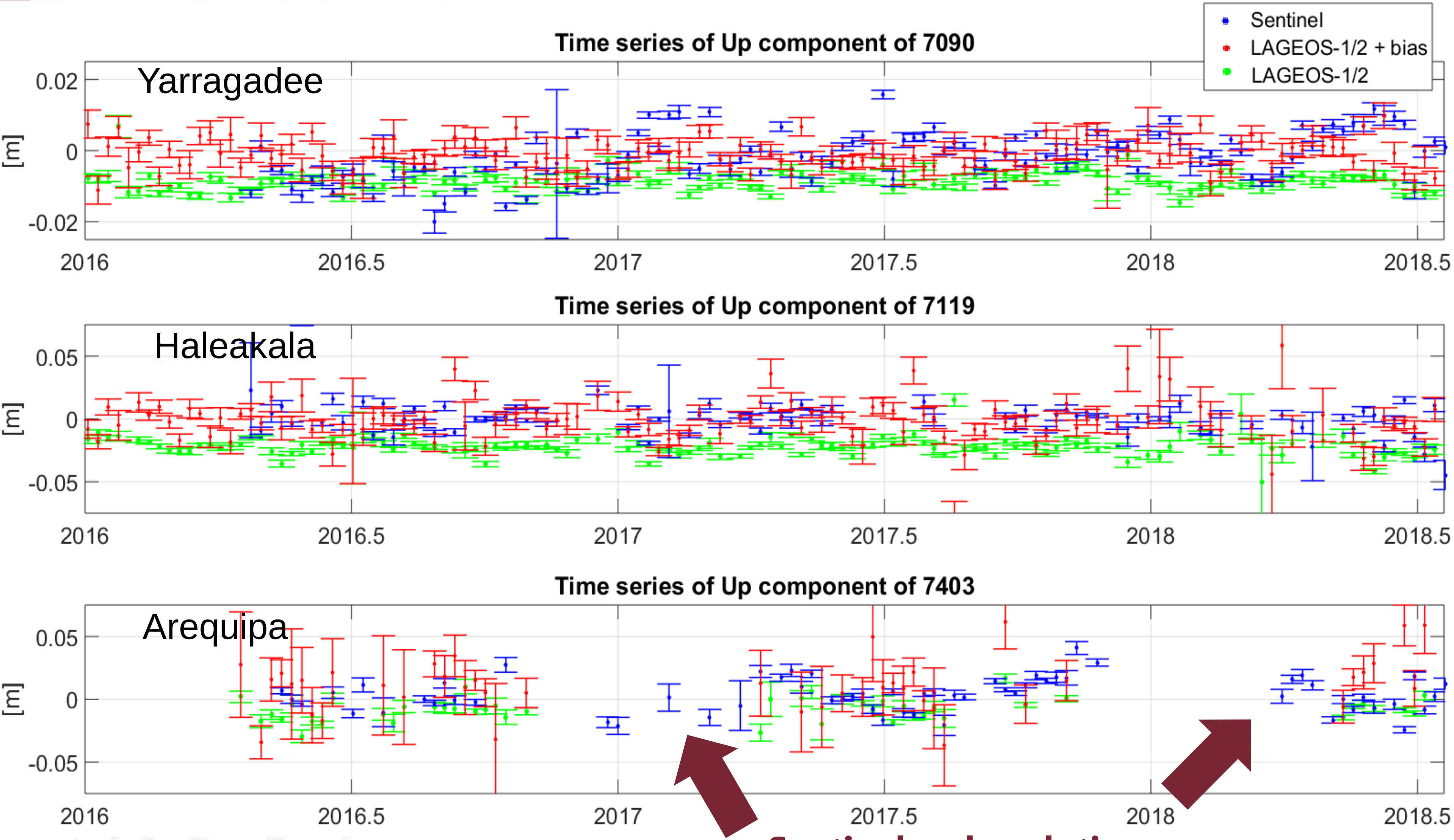
Determination of the geocenter motion is possible using the SLR observations to Sentinel satellites, despite:

- **Low number of SLR observations (short passes) and the sparse SLR observing network**
- **Fixed reduced-dynamic GNSS-based orbits of Sentinels**
- **Different reference frames for Sentinel orbits (IGS14) and the ILRS network (SLRF2014)**

The dominating annual signal in geocenter motion (X and Z components) is well recovered by Sentinels.

LAGEOS orbits are estimated. Sentinel orbits are fixed to GPS-based positions.

Comparison to LAGEOS solutions with and without bias estimation



Sentinel-only solutions when LAGEOS not tracked

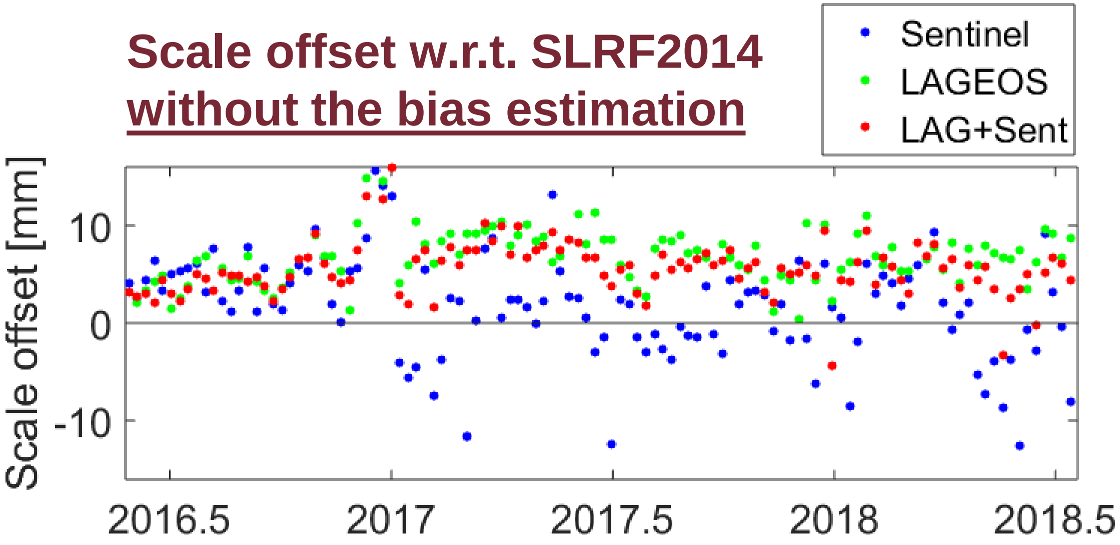
Differences for the Up component w.r.t. SLRF2014 are consistent between Sentinel solutions and LAGEOS solutions with the estimation of biases.

LAGEOS solutions without the estimation of range biases (green) is shifted because of the scale inconsistency between ITRF/SLRF2014 and SLR solutions.

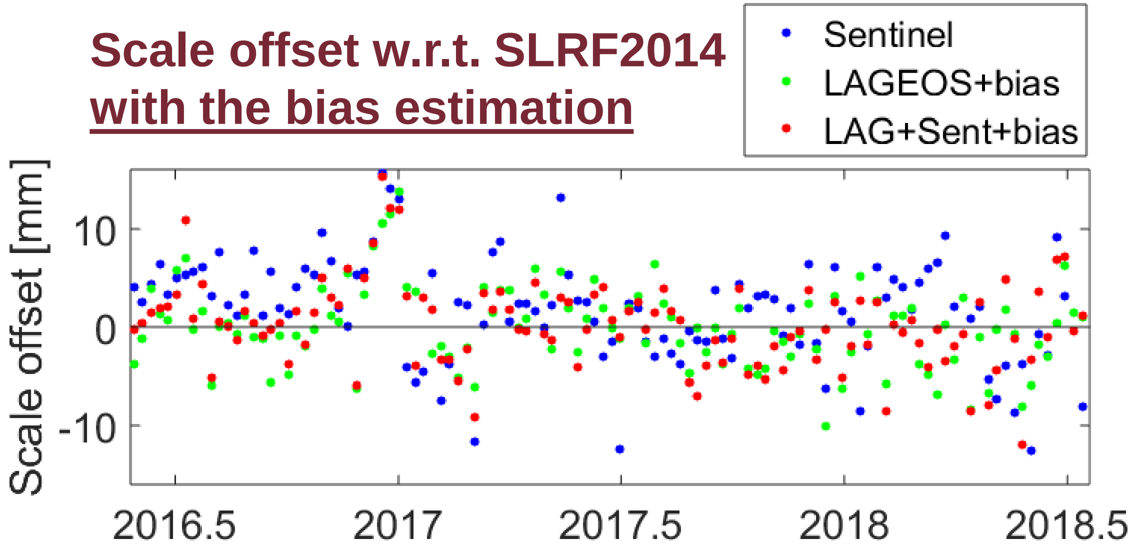
Sentinel solutions are less noisy than LAGEOS with the bias estimation.

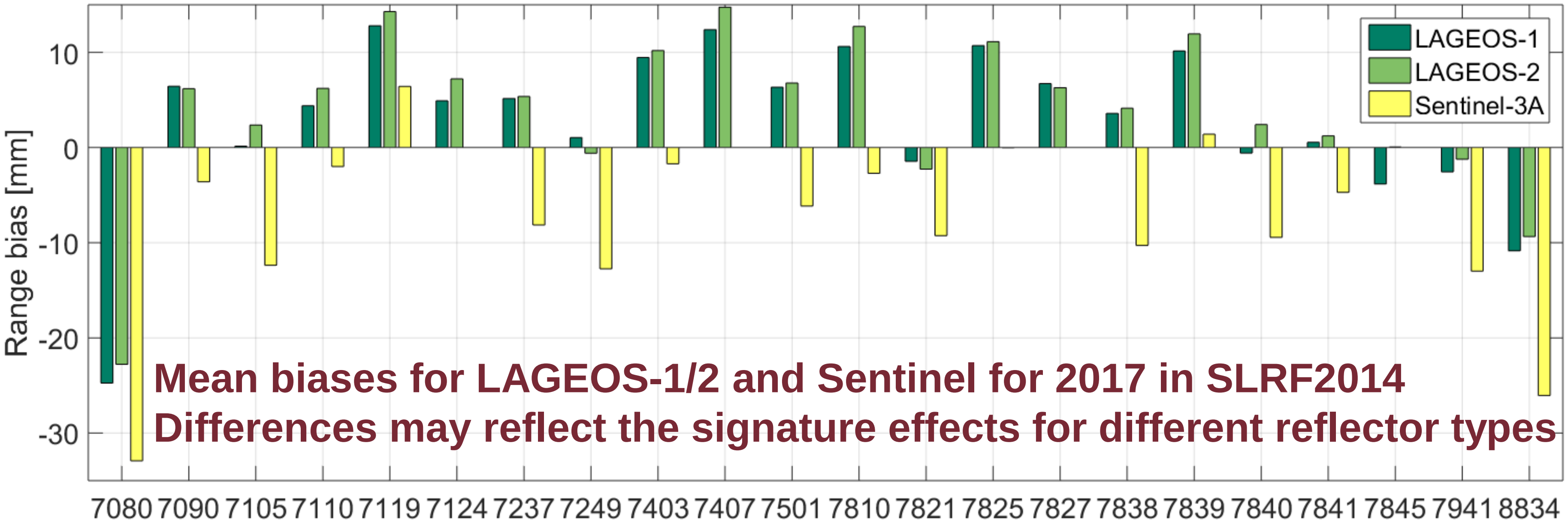
Calibration of range biases and satellite signature effects

Scale offset w.r.t. SLRF2014
<u>without the bias estimation</u>



Scale offset w.r.t. SLRF2014
<u>with the bias estimation</u>





Mean biases for LAGEOS-1/2 and Sentinel for 2017 in SLRF2014
Differences may reflect the signature effects for different reflector types

Most of the SLR stations have positive biases to LAGEOS, e.g., 7090 +6mm, 7119 +13mm, 7810 +11mm, 7825 +11mm, 7839 +11mm. Biases to Sentinel from the combined solution are 7090 -4mm, 7119 +6mm, 7810 -3mm, 7825 0mm, 7839 +1mm.

SLR stations have been providing observations to a large number of new LEO and GNSS satellites

Estimation of global geodetic parameters, such as geocenter coordinates, is possible when using SLR data to Sentinel-3A/B and GNSS-based reduced-dynamic orbits (despite the reference frame incosistency)

Active LEOs can be used for the identification and calibrations of SLR range biases and the satellite signature effects for various targets in the multi-satellite combination

Thank you for your attention

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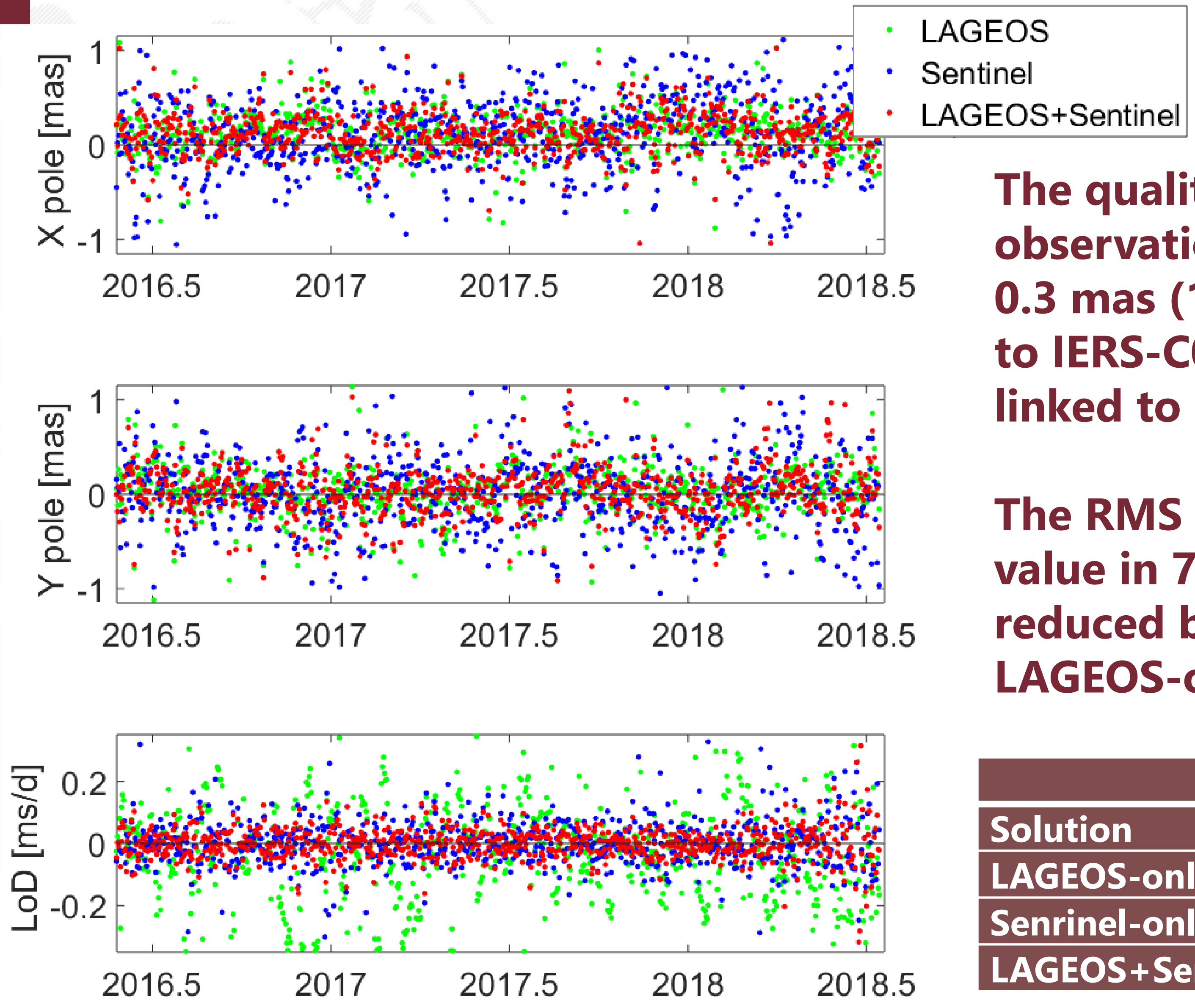
Back-up slides

Earth Rotation Parameters w.r.t. IERS-14-C04 series

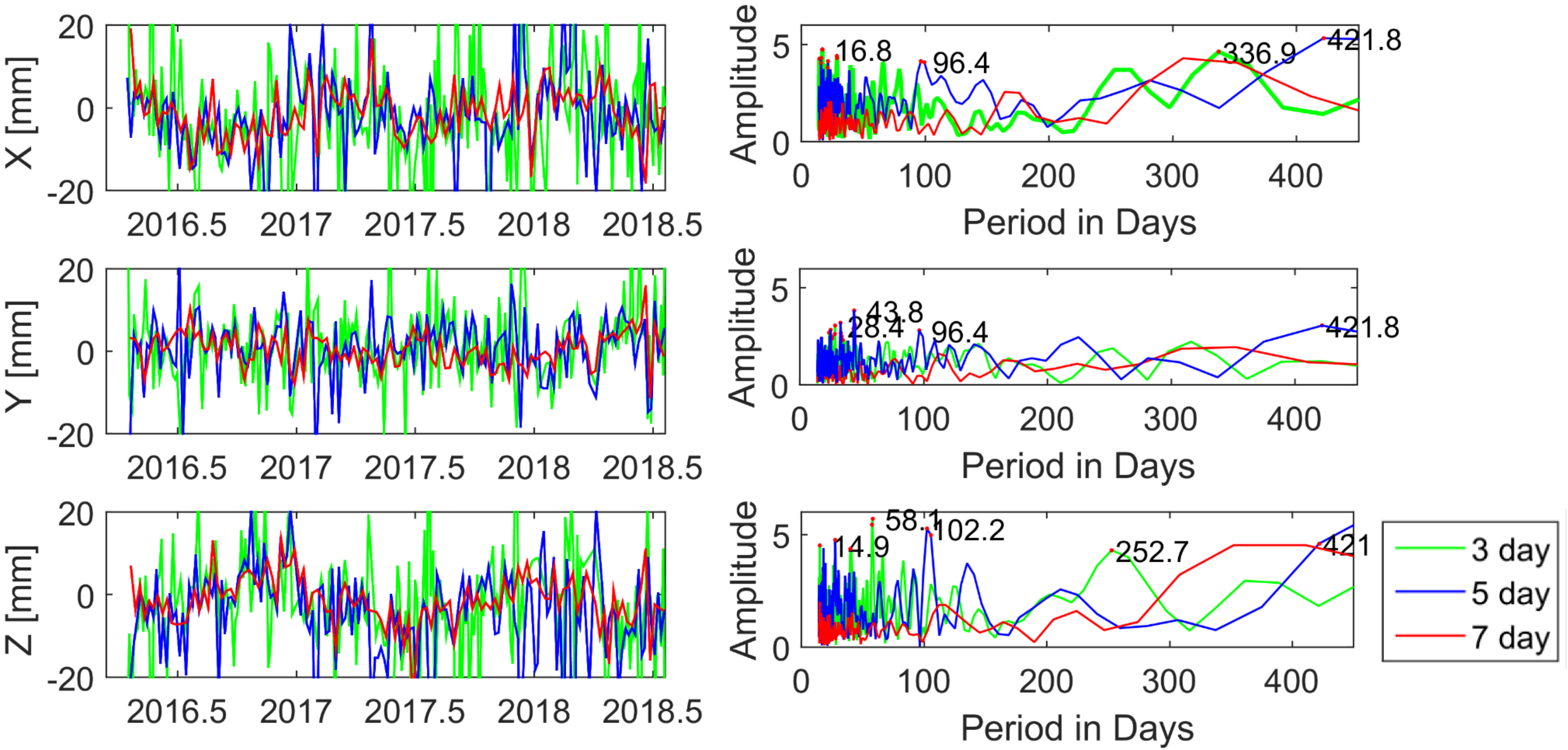


The quality of pole coordinates derived from SLR observations to Sentinel-3A/B is at the level of 0.3 mas (1 cm on the Earth surface) when compared to IERS-C04 series. The Sentinel orbits are, however, linked to IGS14 via GPS observations.

The RMS of LoD (in fact UTC-UT1 with the middle value in 7-day solutions fixed to IERS-C04) is reduced by a factor of 2 when compared to LAGEOS-only solutions.

	X pole [µas]		Y pole [µas]		LOD [µs]	
Solution	**mean**	**RMS**	**mean**	**RMS**	**mean**	**RMS**
LAGEOS-only	128	134	47	166	**-98**	**107**
Senrinel-only	109	320	40	314	**-2**	**63**
LAGEOS+Sentinel	134	138	44	189	**-11**	**67**

Geocenter coordinates based on Sentinel 3A/3B



Station coordinates